FINAL REPORT

FOR

CONTINUOUS SCANNING METEOROLOGICAL CAMERA SYSTEM

FOR ATS

Contract NAS 5-9671

September 22, 1965 to September 10, 1967

Prepared by

ITT Industrial Laboratories
Fort Wayne, Indiana

For

NASA Goddard Space Flight Center
Greenbelt, Maryland

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ABSTRACT

This report presents a chronological review of activities conducted by the ITT Industrial Laboratories in the development of the Image Dissector Camera System for the Applications Technology Satellite. Areas of performance are traced from initial design studies through qualification testing of the prototype camera.

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	BACKGROUND AND INITIAL STUDY	2
3.0	FIRST QUARTER ACTIVITIES	5
4.0	SECOND QUARTER ACTIVITIES	6
5.0	THIRD QUARTER ACTIVITIES	8
6.0	FOURTH QUARTER ACTIVITIES	9
7.0	FIFTH QUARTER ACTIVITIES	10
8.0	SIXTH QUARTER ACTIVITIES	12
9.0	SEVENTH QUARTER ACTIVITIES	14

1.0 INTRODUCTION

Under Contract NAS5-9671, the ITT Industrial Laboratories (ITTIL) has developed an Image Dissector Camera System (IDCS) for operation aboard ATS-C, a spin stabilized, synchronous altitude spacecraft in the Applications Technology Satellite series. Built under the technical direction of the Systems Branch of NASA's Goddard Space Flight Center, this experiment will collect high resolution images of Earth's cloud cover during daylight hours for realtime transmission to ground recording terminals. The system utilizes a built-in sun sensor and a voltage-controlled crystal oscillator to generate precise spin-proportional timing pulses which permit a primary operating mode employing north-south scanning. The camera delivers a composite output signal containing frame sync, line sync, sun pulse, and nutation data in addition to the scene video information. These signals permit the use of a much simplified ground station and also allow the removal of nutational distortions from longitudinally scanned images by simple ground station processing.

This development program was initiated in September of 1965 with a 2 month study of system requirements and parameters and the establishment of design approaches and performance goals. System, circuit, and logic design activities then followed with parallel efforts applied to the engineering model (EM) camera, the bench checkout equipment (BCU), and related test and simulation devices. The first BCU was completed and initial system testing of the EM camera was begun in August 1966. Final acceptance of the EM camera was made in November. Qualification testing of the prototype camera began in December 1966, but several problems (notably corona in high voltage supply, optical focus shift with temperature, and a tube failure during thermal-vacuum testing) delayed the acceptance of the prototype unit until early April, 1967.

This report gives a general review of activities conducted during the consecutive quarterly periods of the program. While technical in nature it is not intended to be the final detailed handbook for the IDC. The complete theory of operation and design details of the system are documented in the Operation and Maintenance Manual for the camera.

2.0 BACKGROUND AND INITIAL STUDY

Prior to the award of the subject contract, ITTIL performed a study (Contract NAS5-3770, Amendment 5) to determine the feasibility of developing a continuous scanning camera for use on a spin-stabilized satellite. This study evaluated the performance characteristics of the ITT Vidissector sensor tube under the operating conditions encountered at synchronous altitude and considered possible limitations which this sensor might impose on the orbital characteristics of a spacecraft. It also considered image distortions which could result from satellite motions and mis-alighments and from the spherical earth as viewed from synchronous altitude. The findings of this previous study indicated the feasibility of development of the camera system described herein.

The initial 2-month study effort under this contract resulted in the Phase I Study Report (PISR) of December 10, 1965 which presented a general description of system electronics, sensor analyses, optical design and selection criteria, and the intended construction and packaging techniques. The system block diagram of Figure 2-1 was developed and, except for the subsequent addition of the sun sensor as an integral system component, has remained unchanged and in use throughout the program as an overall representation of system functions and interrelationships.

The most demanding and significant effort during the study was the conceptual design of a frequency generation unit which would provide the system with a suitable spin-proportional timing reference. System specifications dictated a highly stable and accurate clock source while the wide tolerance (100 ± 40 rpm) on satellite spin rate necessitated a frequency deviation of nearly 3 to 1. Jitter in the sun sensor signal, providing spin rate data, which equalled many camera resolution elements further complicated the timing problem. Consideration of these factors led to the development of a frequency synchronization unit employing closed loop control of a voltage controlled crystal oscillator (VCXO). An adaptive sampled-data feedback system with deadband was devised and implemented with high speed integrated circuit logic elements and a digital-to-analog converter to exert precise control of the VCXO. The discussion of the theory and implementation of this system as well as the related diagrams in paragraph 4.2 of the PISR remains valid for the finalized configuration.

The scan modes and their formats, area coverage, and lens characteristics remain essentially as described in the PISR, although a special lens with a focal length of 49 mm was procured to ensure full field coverage for the cathode of the 1 inch Vidissector. The 1 inch tube was selected with an S-11 photocathode and 0.0007 inch aperture.

While the operations and signal interactions needed for system timing and control are properly described in the PISR, several changes in logic design and signal derivation were made in this portion of the system. The M+1 counter is phased for

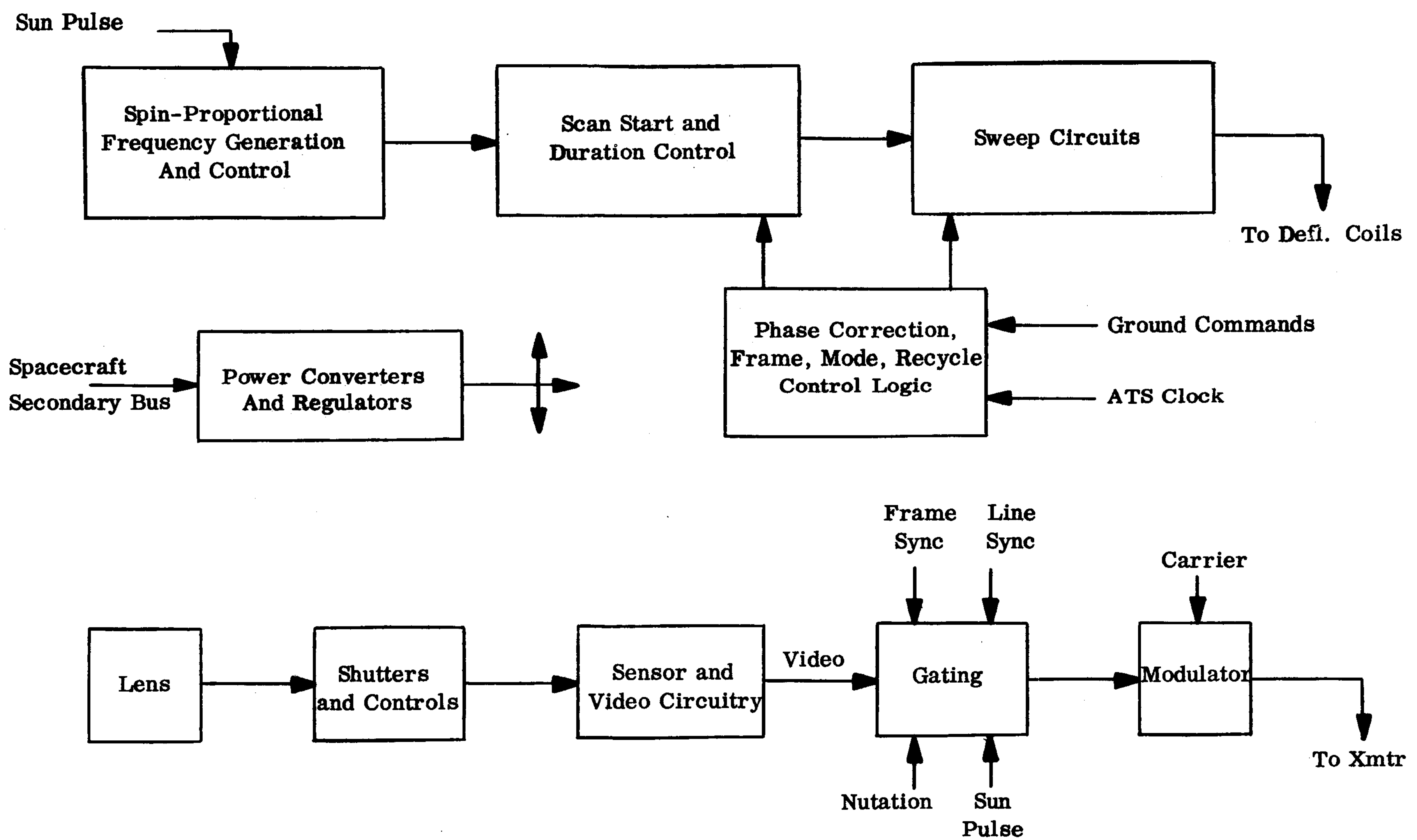
Sun Pulse
Spin-Proportional Frequency Generation And Control
Scan Start and Duration Control
Sweep Circuits
To Defl. Coils
Phase Correction, Frame, Mode, Recycle Control Logic
Ground Commands
ATS Clock
Spacecraft Secondary Bus
Power Converters And Regulators
Lens
Shutters and Controls
Sensor and Video Circuitry
Video
Frame Sync
Line Sync
Gating
Nutation
Sun Pulse
Carrier
Modulator
To Xmtr

Figure 2-1

the correct look angle only at the beginning of each frame by parallel loading from the TOD counter. Extra pulses are then inserted at a 2.64 second rate to update the M+1 counter throughout each frame. The scan period for latitudinal mode is determined by a sense gate on the M+1 counter rather than by a delay circuit as initially planned. The line sync pattern is changed to 16 alternate 1-0 element intervals followed by a 32 element fixed delay before video. Otherwise, the line timing, frame timing, and output data format diagrams are proper.

Printed circuit board construction is precisely as indicated, utilizing two laminations with an internal copper heat sink plane. The mechanical configuration of the camera housing was altered somewhat from that shown, however, with two rows of plug-in boards and fewer box modules.

3.0 FIRST QUARTER ACTIVITIES

Efforts through December, 1965 proceeded on several parallel fronts following the directions established during the study phase. Logic design, circuit breadboarding and analysis, mechanical detailing, sun sensor investigations, and sensor tube testing received concurrent attention during this period. Another significant activity undertaken was the generation of a mathematical model for the frequency synchronization scheme presented in the study report. Both a theoretical analysis developed around a conventional phase-locked loop system and a digital computer simulation of the proposed system were reported in the First Quarterly Report (FQR). The computer model provided a more direct representation of the actual system and proved to be more easily used and understood. Its performance agreed very well with expected system performance and simulation studies were continued to provide further evaluation of system parameters and verification of its capabilities. Detailed requirements and specifications for the VCXO to be used in the frequency sync loop were discussed with vendors and a subcontract for the development of a special unit to fulfill the requirements was prepared.

Logic design and testing of the high speed portions of the frequency loop were conducted with good results. Preliminary design and breadboard evaluations were begun on some of the required analog circuits, primarily the low voltage power supply, carrier generator, and modulator. None of these circuits were finalized, however, and work continued in these areas.

Exposure of camera tubes to simulated sun sources was begun to determine the effects of such exposure on the sensitivity of photocathodes and thus to determine the need for spin-rate shuttering. Initial testing was conducted with a rather poor light source while the development of a more accurate sun simulator was being completed and a test set-up prepared. Since many hours of exposure were necessary to determine long-term effects, only preliminary indications of cathode stability were seen at this time.

Laboratory testing and study of various types of sun sensors were in process to determine which type would produce the most accurate and noise-free reference for the timing system. This activity was undertaken as a result of the decision to provide an improved sun sensor as an integral component of the IDC system.

The mechanical structure of the camera was designed and the parts for the housing were being fabricated. The assembly as shown in the FQR received later revisions in the location of mounting pads, arrangement of connectors, and in the transposition of the scene and sun sensing systems. The mechanical support and mounting structure for the tube and coil system was also detailed and received only minor modifications subsequently.

Also during this period, the design of the Bench Checkout Unit (BCU) for the camera was receiving concerted attention under a full parallel effort.

4.0 SECOND QUARTER ACTIVITIES

During the months of January, February, and March of 1966, major emphasis continued on development and breadboard testing of system logic, circuits, and other subassemblies for the camera as well as design finalization and initial construction efforts on the BCU. Computer simulation studies of the frequency synchronization system were continued with an improved noise simulation technique. These studies were concluded with sufficient data compiled to show system operation under various noise conditions which indicated the significance of the deadband to maximum noise relationship. The deadband to be provided in the actual system would be determined by the stability characteristics of the sun sensor unit which had yet to be finalized.

A full breadboard of the frequency synchronization loop was operated during this period which demonstrated the response expected and verified the implementation of the sync system. Printed circuit cards for this and other portions of system logic were under fabrication for the EM camera. Efforts were underway to improve the operation of the digital-to-analog converter units through the use of inverted mode switches. This technique proved quite satisfactory in providing more accurate and temperature-stable operation.

The low voltage power supply development was nearly completed with a dual transformer design which was capable of handling the power required with miniature components while still operating with efficiencies of about 70 percent. Difficulties continued to be encountered in high voltage supply design, however, due to the large capacity resulting from the high turns ratio needed to produce the -1600 volt output.

Exposure of photocathodes to high intensity light simulating the scanning of the sun in orbital operation was continued with preliminary results indicating that the degree of degradation was not sufficient to warrant the complication of spin-rate shuttering. Testing was to be continued, however, to accumulate data on more tubes and for longer exposure periods before reaching a firm conclusion in this area. Another series of tests was conducted that showed temporary or short-term photocathode fatigue occurring immediately after solar exposure was completely negligible.

Investigations into various types of sun sensor assemblies were carried to the point where no well-founded selection could be made with the test results and data available. Three different units were therefore being fabricated so that comparative tests and evaluation of these actual models could be made. Descriptions of the three configurations are contained in the Second Quarterly Report.

Also contained in this report is the outline drawing for the IDC. The three point mounting configuration shown was later directed to be changed to a four point mount. One further mechanical modification was to be subsequently required after the camera base became the mounting surface for the Nutation Sensor experiment. Vibration surveys showed that a stiffener bar was needed across the lower mounting bracket to provide a more solid platform on which to mount that unit.

Construction of the BCU was underway and the final electrical design details of this unit were being processed. The requirements for the mechanical portions of this unit proved to be extremely demanding, however, and it became necessary to compromise somewhat on the capabilities to be provided in the simulation of satellite rotation. The stability and accuracy needed in a rotating mechanism to adequately test the camera's timing and scan control circuits were adjudged to be unobtainable within the time and economic limits of the program. Thus the spin simulator development continued on the best configuration possible with state of the art components. In fabrication during this period was the film transport mechanism used in the BCU to incrementally move a film pack across the line scanned CRT to obtain a full frame photograph of camera video.

5.0 THIRD QUARTER ACTIVITIES

Concerted effort was applied during the third quarterly period of April, May, and June, 1966, in striving for completion of the first BCU and in beginning fabrication of the EM camera. The electrical portions of the BCU were nearly completed with some checkout and certain circuit refinements remaining in process at the close of the period. Progress on the film transport, spin simulator, and target collimator was not as great, however, although all of these devices were in various fabrication and assembly phases. The design features of the rotating mirror and collimator are described in the Third Quarterly Report which also contains the component list for the film transport.

The design of the digital-to-analog converter embodying inverted mode switches was completed during this period and is shown in the report referenced above. The availability of this design permitted the completion of the counter-converter logic for both the sweep-generating element counter and the updown counter for VCXO control. The engineering model camera then began to take shape as the six circuit cards comprising the frequency sync loop were all fabricated and interconnected through a hard-wired mother board. The loop demonstrated good acquisition and locking characteristics although a race condition was observed occasionally during R count transitions. This problem was eliminated with a minor change in the crossover and control gating. Discussion of this modification and the schematics of the logic cards utilized in the loop are presented in the Third Quarterly Report.

Comparative testing of three different sun-sensor models was conducted and the unit selected for use received final mechanical design attention in preparation for fabrication. The unit selected utilizes a 3/8 inch objective lens, a precision machined lucite light guide having a 3 mil wide aperture slot, and three parallel connected solar cells as the detector. Other details of this unit, other sensors tested, and the observed results of the tests are contained in the earlier referenced report. This report also contains a summary of time and test results obtained in the continuation of the photocathode fatigue studies using simulated sun scanning.

Other design activities conducted during this period and reported in the Third Quarterly Report include the optical design data for a quartz window to provide radiation shielding for the camera lens, the specification for the minus blue haze filter to be deposited on this window, a thermal analysis of the heat transfer characteristics of the laminated circuit cards, the four point mounting configuration change in the camera housing, the modification to the heat sink tie down straps for the circuit boards, and a summary of system weights.

6.0 FOURTH QUARTERLY ACTIVITIES

During this period ofJuly through September, 1966, the first BCU was completed, tested, and accepted by NASA. The fabrication of the EM camera was completed and full system testing begun. Construction of the housing and most other mechanical parts of the prototype camera were also completed. Revisions to circuits developing from EM troubleshooting were being incorporated into circuit board artwork for prototype fabrication. While a few prototype cards were being assembled, lamination process difficulties reduced the yield of acceptable cards during this time.

The Fourth Quarterly Report contains a sketch of the EM camera which identifies and locates each of the subassemblies utilized therein, exploded views and schematics of both high and low voltage power supplies and the sun sensor assembly, schematics of the analog circuit assemblies used in the EM camera, and diagrams and schematics giving an overall representation of the BCU. This report is therefore a good reference for the configuration of the EM camera and for the general characteristics of the BCU.

Prime emphasis was placed on the testing, troubleshooting, and performance improvement of the EM camera. Progress was not as rapid as desired, however, for the incorporation of all telemetry circuits, initializing functions, and general integration of the various subassemblies required considerably more time than expected. Also, this first full mating with the BCU required the cleanup of all interfaces and the proper operation of the related simulation devices. A flashing sun simulator was developed to exercise the sun sensor assembly and to provide an accurate timing reference for the frequency synchronization system.

The collimator was completed and its performance characteristics determined to allow proper evaluation of camera response to its projected images. Considerable testing and modification was required in obtaining acceptable performance from the film transport mechanism. Initial operation showed wide variations in the incremental step size during line by line film advance. After changing from mechanical over-running clutches to electrically operated magnetic units, several other changes were also necessary before this device demonstrated the desired operation. Initial tests of the rotating mirror assembly indicated rather poor rotational accuracy, attributed to variations in the power line. Substitution of a low frequency generator and power amplifier did not produce great improvement. Further tests were to be conducted after a more stable frequency source using logical division of a precision reference was constructed.

The Fourth Quarterly Report contains more detailed discussions of all of the above-mentioned areas of concern arising during this initial period of overall camera and test system operation. Also included are some of the problems encountered early in camera system testing and the manner in which they were rectified.

7.0 FIFTH QUARTER ACTIVITIES

The fifth quarter of contract activity, October through December, 1966, marked the transisition from the EM to the prototype phase of the program. The EM camera test, begun in the fourth quarter, was completed, and this camera was accepted by NASA. Work continued on fabrication of prototype model electronic and mechanical subassemblies, and the formal bench testing of these subassemblies. Late in the quarter the full prototype camera was assembled and system test started. Preliminary thermal-vacuum testing was conducted and several modifications in camera design incorporated as a result of these tests. A thermal analysis was performed on the IDC. From this study a thermal-vacuum test housing for the camera was designed utilizing a thermoelectric temperature controller. Design effort was essentially completed on the mechanical spin simulator. The first test collimator using the Schneider Xenotar lens system was fabricated and assembled early in the fifth quarter.

Most EM system test problems were concerned with improving camera resolution response and lowering objectionable noise levels. Resolution was improved at the edges by incorporating a dynamic focus circuit in the focus current regulator design. System noise was lowered by revising the ground layout in the camera. Grounds for each camera functional block were returned separately to a common tie point at the low voltage power supply. Video levels from the video amplifier through the modulator were raised to further reduce the effects of noise.

Radio frequency interference tests were conducted on the EM camera utilizing ITTIL screen room facilities. The r-f level at frequencies from 100 mhz to 5.2 ghz was set to give a field intensity of 1 volt per meter at a distance of 1 foot from the transmitting antenna. The EM was operated in this environment as this range of frequencies was slowly swept. No erratic or unusual behavior was detected in camera operation during these tests.

Early in November the EM acceptance test was completed. EM camera performance is summarized by the following data:

Center Resolution:	15% Modulation at 1000 lines 40% Modulation at 700 lines
Dynamic Range:	100:1 (13 $\sqrt{2}$ Gray Scale shades)
Signal-to-Noise Ratio:	15db at 100 ft. L. highlight brightness 35db at 10,000 ft. L. highlight brightness
Shading:	±20%
Power:	19.2 watts

Prototype electronic printed circuit cards were completely fabricated and tested during this quarter. Each subassembly was tested according to an electrical test procedure which included testing at both high and low temperatures (+55 degrees C and -5 degrees C). The prototype housing was fabricated and wired, and following assembly of all cards and modules into the housing, operational testing of the entire prototype camera was begun.

Prototype system tests preparatory to formal qualification resulted in the elimination of several electrical temperature problems. During a "dry run" thermal-vacuum test which was conducted, camera performance was found unacceptable in several areas. Each of the problem areas was the consequence of subassembly interface conditions which had not been previously subjected to temperature testing. Several cases of marginal biasing or component values existed which caused undesirable degradation of camera parameters at the temperature extremes. Relatively minor circuit modifications were successful in correcting these marginal conditions. Final preparations, including conformal coating of the cards and staking of wires were performed, readying the camera for the start of formal prototype qualification testing.

Based on the thermal analysis completed during this quarter the test equipment design for thermal-vacuum testing was initiated. Single-stage thermoelectric cooling was deemed adequate and a cooling system designed utilizing the Melcor CP2-15-10B thermoelectric module. Wall temperature achieved with this system was -36 degrees C to obtain a camera temperature of -5 degrees C in the vacuum chamber by radiant cooling only.

Further work was done during the quarter on the spin simulation system which resulted in a rotational system with a spin rate constant to within 1 part in 30,000. While this accuracy fell short of the full camera capability of 1 part in 300,000, it was adequate to provide a spin system which allowed operation of the camera in a mode that produced a raster type picture similar to that which would be obtained aboard the spin-stabilized ATS spacecraft.

8.0 SIXTH QUARTER ACTIVITIES

The months of January, February and March 1967 were concerned almost solely with qualification testing of the prototype camera. The qualification test program included testing in the following environments:

Thermal-Vacuum (300 hours)

Vibration

Acceleration

Humidity (24 hours)

Difficulties were encountered at various stages of the qualification program which required component changes (including the image dissector tube), electrical and mechanical design changes, and various degrees of environmental test repetition. However, by the end of the sixth quarter, the prototype camera had successfully passed the full 2 week thermal-vacuum cycle, a complete three axis sine and random vibration test, and all acceleration and humidity tests. The Sixth Quarterly Report details the environmental conditions to which the camera was subjected.

The thermal-vacuum environment proved perhaps most difficult of the qualification tests in that most performance and design problems were encountered here. Two sources of high voltage breakdown were found during the testing of the camera. One was inside the high voltage power supply because of two dissimilar compounds that were being used as potting material. The other was traced to a pinched high voltage lead outside the tube envelope. Appropriate corrections were made which eliminated the breakdown.

A problem involving optical focus shift with temperature was experienced, resulting in degradation of camera resolution. Some portions of the tube mounting were redesigned in order to eliminate this shift. A full 300 hour thermal-vacuum test was successfully passed late in the sixth quarter.

Vibration tests caused three failures before successful negotiation was achieved. A transistor in the video amplifier shorted, the external slotted tube mask rotated, and the nutation sensor failed due to vibration levels amplified by the mechanical configuration of the camera housing. Replacements and modifications were made to correct these problems.

No direct failures were traced to acceleration testing; however, the Vidissector tube developed a high resistance connection to the photocathode shortly after exposure to this environment which resulted in a change in electrical focus with varying light input. The extreme resolution variation which resulted required the replacement of the tube.

The complete humidity environmental test was run without difficulty.

Minor design changes reflecting refinements or changes in system philosophy were also made in the prototype camera during this quarter. A change was made in the direction of the time-of-day ramp vernier correction to the horizontal sweep; the reference voltage for the sweeps and the oscillator was stiffened by means of double regulation; and provisions were made to inhibit changes in the R count stored in the R Buffer during an active frame.

As of the end of the sixth quarter then, the prototype qualification test program was approaching completion with only some reduced level acceleration and vibration tests remaining in addition to the final acceptance test.

9.0 SEVENTH QUARTER ACTIVITIES

During the early part of this quarter, the qualification test program for the prototype model IDC was completed and the final acceptance Bench Check Test was run. On April 10, 1967, the prototype camera was shipped to the ATS prime contractor.

The qualified prototype IDC exhibited essentially the same performance characteristics as the engineering model. These performance data are summarized below:

Center Resolution:	18% Modulation at 1000 lines 40% Modulation at 700 lines
Dynamic Range:	100:1 (13 $\sqrt{2}$ Gray Scale shades)
Signal-to-Noise Ratio:	15db at 100 ft. L. highlight brightness 35db at 10,000 ft. L. highlight brightness
Shading:	± 15%
Power:	18.3 watts